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THE COMPETITION-AMONG-RELATIONS-IN-NOMINALS THEORY OF CONCEPTUAL COMBINATION: IMPLICATIONS FOR STIMULUS CLASS FORMATION AND CLASS EXPANSION

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One way in which new concepts are added to the conceptual system is through conceptual combination. The competition-among-relations-in-nominals (CARIN) theory (Gagné & Shoben, 1997) proposes that conceptual combination involves specifying a thematic relation (e.g., noun MADE OF modifier) to link the constituent concepts (e.g., *chocolate* and *bee*). This theory claims that relations have different strengths for various concepts that correspond to how often a modifier and relation have been paired in previous encounters with combined concepts and that this relational knowledge strongly affects the ease with which combined concepts can be formed. A mathematical model that incorporates key claims of the theory is presented, and empirical findings that are relevant to evaluating the CARIN theory are reviewed. The parallels between the CARIN theory and approaches to stimulus class formation are also discussed.

Key words: conceptual combination, stimulus class formation, class expansion, noun compounds, math modeling

Because the world is constantly changing, the conceptual system must also change. There are at least two ways in which the conceptual system can change. First, direct experience with new categories can lead to the acquisition of new concepts through *category learning*. Second, new concepts can be acquired by combining existing concepts through *conceptual combination*. Conceptual combination is a process whereby two or more concepts are combined to create a new concept. For example, *tin* and *bottle* can be combined to form *tin bottle*. Likewise, *headache* and *exam* can be used to create *exam headache* and *chocolate* and *carrot* can be used to form *chocolate carrot*. Notice that combined concepts can be expressed as two-word phrases. In English, the first word is called the modifier and the second word is called the head noun. During conceptual combination, the head noun (e.g., *bottle*) is modified in some way by the modifier (e.g., *tin*). The modifier often specifies the way in which the head noun differs from other members of its category (Clark, 1987; Gelman & Markman, 1985). For example, a tin bottle differs from most bottles in that it is made of tin rather than plastic or glass.

Although seemingly straightforward, the processes underlying the creation of combined concepts are neither trivial nor transparent. First, the meaning of the individual concepts is often altered by the combination (e.g., the meaning of *corporate* is noticeably different in *corporate lawyer*, a lawyer who is specializes in corporate law, and *corporate stationery*, stationery used by a corporation). Second, combined concepts often have properties that are not part of either original concept (e.g., a *stone squirrel* is ornamental, even though neither stones nor squirrels are generally ornamental). Consequently, properties of newly constructed concepts are not necessarily inherited from the two original concepts, as researchers once thought. In cases in which a feature is part of one of the original concepts (e.g., both *chocolate* and *chocolate carrots* melt), there needs to be an explanation for why this feature is inherited in these cases but not in other cases (e.g., *chocolate factory*). Thus, although one might think that this modification would be a simple process of adding properties of the modifier to those of the head noun, this has not turned out to be the case (Medin & Shoben, 1988; Murphy, 1988, 1990). Instead, the interpretation of combined concepts involves an interaction between the two constituents rather than an additive process. If the process

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were additive, then all properties of the new combination would be inherited from the constituent concepts.

Although there has been much focus on category learning (Komatsu, 1992), relatively little is known about how concepts combine. Nonetheless, there is much to be learned by studying conceptual combination. The area of conceptual combination is especially well suited for addressing the issues of how concepts are generated and how the conceptual system changes over time. Indeed, determining how concepts combine to form new concepts helps researchers understand how the conceptual system adapts and expands. In addition, conceptual combination historically has been an important test case for psychological theories of concepts because the process reveals information about conceptual structure. For example, a conceptual combination task, in which subjects produce an interpretation for a novel modifier–noun combination (e.g., *earthquake school*), has been used to identify differences between the structure of superordinate and basic level concepts (A. B. Markman & Wisniewski, 1997).

The previous paragraph summarizes the contribution that research on conceptual combination has made in the human cognitive psychology literature. Can this area of research contribute to other domains, such as stimulus class formation? Much of the work on stimulus class formation has focused on the relations between specific stimuli. For example, researchers have examined the conditions in which Stimulus A is equivalent to Stimulus B (see, e.g., Sidman, 2000). Conceptual combination appears to involve a similar mechanism in that conceptual combination involves forming a relation between two separate constituents (e.g., forming *chocolate rabbit* involves conjoining *chocolate* and *rabbit*). In this sense, modifiers are functionally equivalent in that they all modify a head noun (e.g., *mountain* and *chocolate* can both modify the head noun *rabbit*). On the other hand, it is important to note that modifiers are nonequivalent in that the specific relation between the modifier and head noun can differ (e.g., *mountain rabbit* is a rabbit that LIVES in the mountains, whereas *chocolate rabbit* is a rabbit that is MADE OF chocolate). The nature of these relation classes has important implications for the formation of novel combinations (Gagné, 2000; Gagné & Shoben, 1997).

In addition to providing information about the nature of relation classes, conceptual combination research provides insight into class expansion. Most existing research on human stimulus class formation examines the acquisition of isolated repertoires. For example, stimuli become interchangeable in the formation of artificial equivalence classes; there is mutual selection in matching-to-sample procedures, and functional properties (such as discriminative control) propagate through the class. This research approach, however, has provided little evidence about what happens when stimuli are conjoined to fulfill separate functions that might compete or blend. Thus, relatively little is known about how members of equivalence classes can be combined to form new classes that are not equivalent to the members of the constituent classes. For example, *chocolate* and *bird* can be joined to form *chocolate bird,* and this new item is a member of class that is not equivalent to either constituent class (e.g., *chocolate* and *bird*). The problem of class expansion has not received much attention in the literature on stimulus class formation. Because conceptual combination involves blending repertories that were acquired separately, research on conceptual combination can help researchers examine class expansion.

Another way in which this research can contribute to work on stimulus class formation is by providing procedures for examining complex word and relation structures that are acquired over many years. Dymond and Rehfeldt (2001) have argued that researchers interested in derived stimulus relations should use a variety of procedures and techniques. Conceptual combination is heavily dependent on the relation between the modifier and head noun. Consequently, using the methods that have been derived for studying conceptual combination is especially appropriate for understanding both the types of relations that can exist among stimuli and the formation of new stimulus classes.

Researchers interested in stimulus class formation in humans have predominantly used a simple-to-complex strategy in which conceptual behavior is constructed from the "ground up." For the most part, this approach has involved the construction of artificial stimuli. An advantage of this work is that the researcher is able to control and manipulate all aspects of the stimulus structure. A drawback of this approach is that it is often extremely difficult to use artificial language-manipulation studies to mimic the extensive learning histories that people have with natural verbal stimuli. Thus, it is sometimes difficult to use this ground-up approach to study more complex phenomena in the natural environment. Therefore, it is useful to supplement this approach with a complex-to-simple approach such as the one that is used to address phenomena such as conceptual combination. In this paper, I present an approach that may encourage researchers to extend existing stimulus class formation procedures by taking into account learning histories with natural stimuli.

Although I will not be providing a behavior-analytic interpretation of conceptual combination based on stimulus class research, the ideas that I will present have implications for such research. In particular, I will present a relation-based approach to conceptual combination that can be used to better understand class expansion. This approach forms the basis of the competition-among-relations-in-nominals (CARIN) theory of conceptual combination (Gagné, 2000; Gagné & Shoben, 1997). In this research, I address the problem of how humans respond to previously unknown modifier–noun phrases. Even with no previous history with specific modifier–noun pairings (e.g., *chocolate bird*), humans are able to interpret such phrases. The approach used in this research allows me to study complex relation ''classes'' by examining not only the relation between two stimuli but also the nature of relation classes. In this paper, I demonstrate that thematic relational information is a key contextual variable in the formation of novel combinations. In addition, I show that the relative frequency of the relation in combination with the modifier (rather than with the head noun) affects the time required to respond to a novel combination.

A RELATION-BASED APPROACH TO CONCEPTUAL COMBINATION

Because the CARIN theory is a reaction against previous approaches to conceptual combination, I will begin by briefly outlining these earlier approaches. The earliest theories of conceptual combination used a compositional approach that asserts that combined concepts are formed by conjoining sets of attributes from the constituent concepts (Hampton, 1988, 1997; E. E. Smith & Osherson, 1984). For example, these theories claim that merging information from *brown* and *apple* forms *brown apple*. Several predictions of these theories, however, have not been supported by the data. For example, compositional theories predict that the order of concepts in a phrase does not affect conceptual combination because order does not alter the attributes of the constituent concepts. Contrary to this prediction, conjunctive concepts show a noncommutativity effect such that the concept *Xs that are also Ys* (e.g., birds that are also pets) is not identical to *Ys that are also Xs* (e.g., pets that are also birds) (Hampton, 1988; Storms, De Boeck, Van Mechelen, & Ruts, 1996; Storms, Ruts, & Vandenbroucke, 1998). Instead, a greater emphasis is placed on the concept in the relative clause; for example, more weight is placed on *pets* than on *birds* for the phrase *birds that are also pets*.

More recently, schema-based theories have emerged as an alternative to compositional theories. Proponents of these theories (Murphy, 1988, 1990; Wisniewski, 1996) propose that the head noun is a schema, and that during conceptual combination, a specific dimension within the head noun's schema is selected and its value is changed to match the value present in the modifier. For example, the value in the FUEL dimension is changed to *wood* for the combination *wood stove*. These theories incorporate the use of world knowledge to explain how the various slots within the schema become altered during conceptual combination and to explain why conceptual combination is not purely compositional. World knowledge is a complex network of causal and explanatory links (see Murphy & Medin, 1985). To illustrate, world knowledge would include the information that birds have wings so that they can fly.

A serious drawback to schema-based theories is that they rely heavily on knowledge structures but do not clearly specify the experience that created such structures. As Murphy (1988) points out, the schema modification model ''refers to people's world knowledge in a rather unconstrained manner'' (p. 554). The question arises as to whether it is possible to specify more precisely which aspects of world knowledge affect conceptual combination. Thus, in my research I have attempted to identify which aspects of a person's previous experience influence the ability to create new concepts.

To address this shortcoming of schema-based theories, I propose that one aspect of world knowledge that is especially critical to conceptual combination is relational information about how objects, people, and so on interact. The main assumption of the CARIN theory (Gagné, 2000; Gagné & Shoben, 1997) is that conceptual knowledge is composed of individual concepts plus relations that serve to link the concepts. This repertoire of relations among previously encountered stimuli is used to select a relation that links two constituent concepts during the formation of a new combined concept. I should point out that this ''selection'' is not a conscious choice. That is, the participant is not actively deliberating which relation should be used. Instead, the term *selection* refers to using a particular thematic relation to form a link between the modifier and head noun. This interconnected structure, which consists of a modifier, thematic relation, and head noun, forms a new combination. For example, *chocolate bee* is formed by using the thematic relation noun MADE OF modifier to link *chocolate* and *bee*. However, *honey bee* is formed by using the relation noun MAKES modifier. As will become evident momentarily, this approach is experienced based in that the modifier concept's past involvement in combined concepts influences the ease of creating a new combined concept using that modifier.

I propose that past experience with various combined concepts gives rise to a network of relations that indicates the typicality of each relation for a given modifier. To illustrate, the concept *mountain*, when used as a modifier, typically denotes a locative relation, but can, in some case, denotes an ABOUT relation (as in, *mountain magazine*). Knowledge about the modifier's past usage with various relations is called the modifier's relational distribution, and this distribution is used to determine which relation is used during the conceptual combination process. There are two aspects of language use that affect this relational distribution. First, people encounter phrases that consist of a particular modifier with a particular relation. For example, *mountain cabin*, *mountain goat*, and *mountain stream* are three examples of combinations using the modifier *mountain* and the locative relation that an individual is likely to encounter during his or her lifetime. A second aspect of language experience that affects relational knowledge is language production. That is, there are occasions that prompt the use of a participant modifier with a specific relation. For example, a person might need to distinguish between goats that live on farms and goats that live in the mountains. This situation might prompt the person to pair *farm* with the locative relation to form *farm goat*. This pairing would increase the association between *farm* and the locative relation. To summarize, one of the CARIN theory's main claims is that the modifier's past usage in a community of language users (e.g., North American speakers of English) with various relations strongly affects the likelihood that a given relation will be used for a particular modifier.

According to the CARIN theory, relations compete with one another such that relations that are more frequently used with the modifier are more likely to be used to link the constituent concepts than are less frequently used relations. The difficulty of creating a combined concept is a function of the relative strength of the required relation. Gagné and Shoben (1997) proposed that the frequency of a relation for a particular concept is a reasonable index of strength. Thus, the CARIN theory posits that, other things being equal, it is easier to combine two concepts when the required relation is highly frequent for the modifier than when it is not frequent. For example, the locative relation (noun LOCATED modifier) is a highly frequent relation for the concept *mountain*. Therefore, it should be easier to interpret *mountain bird* (a bird in the mountains) than to interpret *mountain magazine* (a magazine about mountains). In a subsequent section of this paper, I present empirical studies that test this prediction and will provide details about how frequency was determined.

Absolute frequency, however, is not the only factor that affects the ease with which concepts can be combined. The strength of the other relations in the modifier's relational distribution also plays a role. To illustrate, the frequency of the most used relation for *headache* and *juvenile* is almost identical (33%

and 34%, respectively). The most frequently used relation for *juvenile* is noun FOR modifier. For *headache* two relations (modifier CAUSED BY noun and noun ABOUT modifier) are tied as the most frequent relation. This implies that the ease of selecting the most frequently used relation for combinations using these two modifiers would be equivalent. The frequencies of the second and third most frequent relations, however, are 33% and 21% (noun FOR modifier) for *headache* and 20% (noun HAS modifier) and 15% (noun ABOUT modifier) for *juvenile*. If relations compete for selection, then it should be more difficult to use the most frequent relation for *headache* than for *juvenile* because the frequencies of the competing relations are higher for *headache* than for *juvenile*.

The claim that conceptual combination is more greatly influenced by the modifier than by the head noun is contrary to claims made by schema-based theories of conceptual combination. This claim, however, is derived from the fact that the role played by the modifier and head noun constituents differs. The modifier implies a contrast between members of the head noun category and indicates that the head noun must be altered (Gelman & Markman, 1985; E. M. Markman, 1989). For example, the modifier *chocolate* in the combination *chocolate bee* indicates that the primary difference between this particular bee and most bees is that it is made of chocolate. Put another way, the modifier indicates the relevant contrast set (i.e., the set of exemplars from a given category, e.g., *bees*, that are not part of the subset in question, e.g., *chocolate bees*), whereas the head noun provides the category name (E. M. Markman). For these reasons, it seems reasonable to assume that a modifier's past usage with various relations would more strongly influence conceptual combination than would a head noun's past usage.

To summarize, the CARIN theory posits that the ease with which a novel combined concept can be interpreted is heavily determined by two factors. First, it is affected by the overall frequency of the to-be-selected relation. Second, it is affected by the strength of alternative relations. These two factors have been formalized in a mathematical model that was first described by Gagné and Shoben (1997). In this model, relation frequency and dominance are instantiated using an equation based on Luce's (1959) choice rule, in which the strength of the first choice is weighted against the strength of the competing choices. In the CARIN model, the strength index is the proportion of the frequency of the to-be-selected relation (p_{selected}) to the sum of the frequency of this relation plus the three most likely alternatives (p_1, p_2, and p_3). In constructing the index, we followed other applications of Luce's choice rule (e.g., Rumelhart & Abrahamson, 1973) and used exponential decay functions ($e^{-\alpha p}$), where p represents the proportion of combinations in the corpus that used a particular relation and α is a free parameter. Note that this function has the form e^x, where e is the natural logarithmic base. This exponential function was applied to the to-be-selected relation and to the three most frequent relations in the modifier's relational distribution. For example, if the frequency (expressed as a proportion) of a relation was .60, then the function $e^{-\alpha .60}$ was evaluated.

The strength index for a particular relation is the value obtained from Equation 1.

$$\text{strength} = \frac{e^{-\alpha p_{\text{selected}}}}{e^{-\alpha p_{\text{selected}}} + e^{-\alpha p_1} + e^{-\alpha p_2} + e^{-\alpha p_3}} \tag{1}$$

The exponential function is applied to each proportion to instantiate the claim that the number of competing relations, not just the summed frequency of nonselected relations, influences the strength of the selected relation. For example, due to the use of the exponential function for each term in the right side of the formula, the strength index for a situation in which the selected relation is .60 and the remaining relation is .40 is a different value relative to the situation in which the selected relation is .60 is competing against three relations with values of .20, .10, and .10. For ease of exposition, I have not applied the exponential function to each proportion in this example.

To minimize the number of free parameters, Gagné and Shoben (1997) assumed that α was the same for all relations in the model. As the value of α increases, the curve corresponding to the each term in the formula (i.e., $e^{-\alpha p_{\text{selected}}}$, $e^{-\alpha p_1}$, etc.) becomes steeper. This means that the difference in the corresponding Y values is larger between two large proportions (e.g., .90 and .80) than between two small proportions (e.g., .20 and .10). When the model was used to fit the data reported in Gagné and Shoben, the optimum value of α was approximately 36. A more detailed description about how the model was applied to the data sets is provided below in the discussion of relevant empirical findings.

COMPARING THE CARIN THEORY TO MODELS OF ASSOCIATIVE LEARNING AND MEMORY

Although the CARIN theory was not formulated with associative learning principles in mind, some general aspects of the theory can be interpreted in light of such principles; there are several parallels between the CARIN theory and models of associative learning and memory. The first commonality is that the CARIN theory is built on the assumption that focusing on knowledge structures alone is inadequate because they do not provide the information necessary for constructing novel modifier–noun concepts. Instead, focus must also be placed on the experience that creates these structures.

Thus, the second commonality is that the CARIN theory is experienced based in that it makes extensive use of the relations that exist among previously encountered concepts. In particular, information about how often a modifier has been encountered with various relations is the primary source of information in the CARIN model. The frequency of these previous modifier–relation pairings play a central role in determining the ease of interpreting novel combinations.

This aspect of the model corresponds to a prominent theme in the associative learning literature—adaptation to environmental demands. In operant learning, response strength, the momentary probability of a response occurring in a given stimulus context, is a function of the consequences produced by the response in that context (Skinner, 1938). In this sense, the strengthening of behavior is a nonarbitrary outcome that can be traced to the structure of the environment (see Baer, 1981). Similar environmental dependencies have been described for memory and other cognitive processes. For example, studies of directed forgetting in nonhumans can be interpreted as showing stimulus control of rehearsal (Roper & Zentall, 1993). In the typical procedure, training incorporates differential environmental demands in that in one stimulus context (Context 1) remembering facilitates a response that leads to reinforcement and in another stimulus context (Context 2) remembering has no differential consequences. An example of Context 1 would be a traditional delayed matching-to-sample procedure in which a sample stimulus, A, is presented followed by a retention interval. Then, choices of A and B are presented for which the selection of A is reinforced. The procedure for Context 2 is similar except that no comparison stimuli are presented after the retention interval. Notice that, in the first context, remembering Stimulus A is beneficial, but, in the second context, remembering Stimulus A serves no purpose. After a subject has been trained in either Context 1 or 2, a test phase occurs during which surprise presentations of comparison stimuli are inserted into Context 2. Performance on these trials is poor, suggesting that active processes of remembering, forgetting, or both have come under control of the contextual stimuli. The same perspective can be applied to human directed-forgetting procedures, which are structurally similar to procedures with nonhumans but do not arrange explicit reinforcement contingencies for accurate remembering (see Roper & Zentall).

The importance of environmental demands in human memory has also been demonstrated. A variety of studies indicates that memory for words draws upon not only information about the word itself but also information about the context in which the word was encountered (e.g., J. R. Anderson & Bower, 1974; Tulving & Thomson, 1973). The paradigmatic example is the well-known encoding specificity effect, in which studying and testing in a single context yields superior remembering compared to studying and testing in different contexts (Godden & Baddely, 1975; S. M. Smith, 1979; Tulving & Thomson, 1973; Wiseman & Tulving, 1975). This effect is consistent with the view that remembering is relatively strong in contexts in which it has served a purpose.

Environmental demands also play a prominent role in the concept of *need odds* proposed by J. R. Anderson (1990; J. R. Anderson & Schooler, 1991) to account for certain features of human memory. In defining need odds, J. R. Anderson (1990) proposed that context brings to bear implicit statistical information about the frequency with which events have been encountered recently: "Memory uses the pattern of past occurrences to infer which items are most likely to be useful now" (J. R. Anderson, 2000, p. 239). R. B. Anderson, Tweney, Rivardo, and Duncan (1997) provided experimental support for this notion. In their studies, subjects studied lists of digits and retained them for 1, 2, 4, 8, or 16 s. After the retention interval the subjects were asked to recall the items or no test was given. The shape of forgetting functions was predicted by the frequency of testing. This finding indicates that memory performance was influenced by the likelihood that memory served a purpose.

Another way to conceptualize need odds is as follows. The functionality of remembering a given bit of information varies across contexts. In some contexts, remembering is advantageous. For example, remembering might yield the natural rewards of understanding of text or conversation. In other contexts, however, remembering might confer fewer advantages and, in some cases, even interfere with the current task. Consequently, remembering is less likely to occur in these contexts. J. R. Anderson (2000) and others have noted similarities between differential strengthening and the "selection by consequences" of the operant three-term contingency (e.g., Skinner, 1981) and of stimulus–stimulus relations in classical conditioning (e.g., Donahoe & Palmer, 1994). In this sense, the outcomes of studies that demonstrate an effect of need odds (such as the ones by R. B. Anderson et al., 1997) are reminiscent of operant conceptions in which the strength of behavior is a positive function of recent reinforcement frequency (e.g., Nevin & Grace, 2000).

A third commonality between CARIN and models of associative learning and memory is the notion of *competitive strengthening*. Competitive strengthening is an important theoretical construct in the CARIN theory. As is evident in the mathematic instantiation of the CARIN theory, the absolute frequency is only one aspect of the strength index. A more important aspect is relative frequency. As the frequency of one relation increases, the frequencies of competing relations necessarily decrease.

Whereas the preceding discussion about environmental demands could be characterized as asserting that the right kind of environmental experience strengthens tendencies in behavior and cognition, the notion of competitive strengthening suggests that strengthening of one tendency comes at the expense of other, mutually exclusive, tendencies. That is, strengthening is relative rather than absolute. For example, when applied to compound conditioned stimuli, the Rescorla–Wagner model of classical conditioning (Rescorla & Wagner, 1972) asserts that, for each pairing of the compound with an unconditioned stimulus, the amount of conditioning that occurs to the two elements of the compound is proportional to their relative salience (in overshadowing) or relative amount of prior pairing with the unconditioned stimulus (in blocking).

Investigators of operant learning are familiar with competitive strengthening as expressed in Herrnstein's matching law, in which the strengthening of one response via reinforcement is constrained by the strengthening of alternative responses (Herrnstein, 1970, 1990). In the proportional version of the model,

$$\frac{B_1}{B_1 + B_2} = \frac{R_1}{R_1 + R_2}, \tag{2}$$

the B terms reflect the strength (usually expressed as rate) of two responses, 1 and 2, and the R terms reflect the historical frequency of reinforcement of these responses.

Likewise, Davison and Nevin's (1999) elaborated matching model also takes into account the role of situational cues in competitive strengthening. Together with operant research employing a signal-detection framework (e.g., Nevin & Grace, 2000; White & Wixted, 1999), this model implies that each of two simultaneously accessible stimulus contexts set the occasion for a given behavior to a degree proportional to the frequency with which that behavior has been reinforced in those contexts. Typical concurrent reinforcement schedule procedures confound cue strength with response strength (frequency of behavior–reinforcement pairings, as per the matching law), but the two are, in principle, separable. For present purposes, reinforcement frequency in the two stimulus contexts might be thought of as defining the relative need odds for the behavior in these two situations.

Competitive strengthening also is a feature of many accounts of human cognition. Some models of paired associate learning directly address the problem of competing associations. For example, in cases in which a single word cue is associated with two or more possible responses, the responses are assumed to compete for a limited amount of activation, or strength, that can be generated by the cue (J. R. Anderson, 1983, 1990; Raaijmakers & Shiffrin, 1981). Depending on the type of experimental procedure, the strength of a given response to the cue is evident in the probability of making the response (e.g., in free recall) or in the latency to emit the response (e.g., in recognition memory). The origin of this strength is not always clearly specified, but presumably reflects relative need odds inherent in different cue–response pairs (J. R. Anderson, 2000). Perhaps not surprisingly, formal models adopting this perspective bear structural similarity to the competitive-strengthening models of conditioning (e.g., J. R. Anderson, 2000; Gluck & Bower, 1988).

In the preceding paragraphs I have outlined some general commonalities between the CARIN theory and models of associative learning and memory. In the remainder of this section I compare the CARIN theory to two specific models. The claims made by the CARIN theory are conceptually similar to claims made by J. R. Anderson and Schooler (1991) in their discussion of the retrieval of memory structures (see also J. R. Anderson, 1990; Schooler & Anderson, 1997). They argue that performance in memory retrieval tasks can be understood by examining the odds that a particular memory structure is required. The history of the memory structure and context influence the retrieval of memory structures. This history factor has two aspects. One aspect is the frequency with which a memory structure has been encountered. The second aspect is recency. When comparing these ideas to those outlined in the CARIN theory, it is important to note that novel combinations do not yet have stored memory structures. Instead, they must be created based on information about the individual components. Nonetheless, it is possible that some memory structures consist of the modifier concept along with particular relations and that these structures are involved in conceptual combination. For example, interpreting the combination *snowball* might create a memory structure that connects the modifier *snow* with the relation used to interpret this particular phrase (e.g., MADE OF). If so, then this structure might be involved in the interpretation of other combinations using the modifier *snow*. Put in this framework, modifier relation frequency is equivalent to the frequency factor described in Anderson and Schooler's theory, because high relation frequency implies that many of the memory structures containing the modifier contain a particular relation and low relation frequency indicates that few of the memory structures containing the modifier contain the relation. Although early work on the CARIN theory has concerned the role of the modifier's relational history (Gagné & Shoben, 1997), more recent evidence has suggested that the recency of a relation also plays a role (Gagné, 2001, 2002).

The CARIN theory also shares common assumptions with models of choice (e.g., Davison & Nevin, 1999) because one way to view conceptual combination is as a situation in which a person must choose a single relation from a larger set of relations. During conceptual combination, a particular modifier is not always used with a single relation. Instead, there is variability in terms of which relation is most appropriate. For example, the concept *chocolate* can be used to indicate the substance of another concept as in *chocolate bunny*, but it can also be used to denote a product as in *chocolate factory*. Thus, conceptual combination is not a straightforward process in which a modifier is "matched" with a single relation and then this relation is used to link the modifier with the head noun. Instead, a relation must be selected from among a set of alternatives. Put in this context, the CARIN model is consistent with the model proposed by Davison and Nevin. One component of their model is based on an organism's history of reinforcement for different responses. Just as their model includes terms that indicate "what response goes with what stimulus" and "what reinforcer goes with what response,'' the CARIN model includes a term that indicates the frequency with which a relation has been used with a particular modifier.

EMPIRICAL FINDINGS AND THEIR IMPLICATIONS FOR THE CARIN THEORY

The most direct support for the CARIN theory is reported in Gagné and Shoben (1997). Recall that the CARIN theory claims that experience within a verbal community generates a relational distribution for each modifier. Although we did not have access to the exact nature of each subject's learning history, we could estimate it by constructing a corpus of combined concepts. Prior to conducting the experiments, we created a list of novel noun–noun combinations by crossing 91 modifiers with 91 head nouns. Next, we examined each pairing and determined whether it had a sensible literal interpretation. For example, *mountain bird*, *plastic crisis*, and *chocolate bee* are all interpretable. However, *water album*, *nose breeze*, *olive language*, and *smoke alcohol* are examples of items that do not have a sensible literal interpretation. Of the original set of modifier–noun pairings, 3,239 pairs had a sensible literal interpretation and became part of our corpus. Next, we classified each of the interpretable items according to the relation required to link the constituent concepts (see Table 1 for a list of relations). These categories were based on Levi's (1978) relational categories. For example, *plastic bee* was classified as noun MADE OF modifier because it can be interpreted as ''a bee that is made of plastic.'' This corpus was intended to reflect the prevalence of various modifier–relation pairings and head noun–relation pairings and was used to approximate the subjects' learning history with modifier–noun phrases.

Finally, Gagné and Shoben (1997) calculated the frequency with which various modifiers and head nouns are used with each of these relations by counting the number of times that a particular modifier–relation pairing was used and the number of times that a particular head noun–relation pairing was used. For example, the modifier *plastic* appeared in 38 combinations in the corpus. Of these, 28 used the noun MADE OF modifier relation, 7 used the noun ABOUT modifier relation, 2 used the noun DERIVED FROM modifier relation, and 1 used the modifier CAUSES noun relation. After calculating this information for each modifier and head noun in the corpus, we categorized each relation as high or low frequency for each modifier and head noun. To do this, we selected the most frequent relation for a particular word. If that relation was used with 60% or more of the combinations for that word, then the relation was the sole high-frequency relation for that word. If not, we selected the next highest frequency relation until the combined frequency for all selected relations accounted for 60% of the combinations using a particular word. All other relations were considered low-frequency relations. For example, the modifier *juvenile* was used in 49 combinations. The most frequently used relation for this modifier (noun FOR modifier) was used in 34% of the combinations. Therefore, we also selected the next most frequent relation for *juvenile* (noun HAS modifier). Together, these relations accounted for 61% of all combinations using *juvenile*, and, therefore, these relations were deemed high-frequency relations for the purpose of our experiments.

Once the high- and low-frequency relations had been determined for each modifier and each head noun, we selected combinations to fit one of three experimental conditions. The

Table 1

Relational categories used to classify novel noun–noun combinations.

Relation	Example
Noun CAUSES modifier	Flu virus
Modifier CAUSES noun	College headache
Noun HAS modifier	Picture book
Modifier HAS noun	Lemon peel
Noun MADE OF modifier	Chocolate bird
Noun MAKES modifier	Milk cow
Noun FOR modifier	Cooking toy
Modifier IS noun	Dessert food
Noun USES modifier	Gas antiques
Noun LOCATED modifier	Mountain cloud
Modifier LOCATED noun	Murder town
Noun ABOUT modifier	Mountain magazine
Noun DURING modifier	Winter cloud
Noun USED BY modifier	Servant language
Noun DERIVED FROM modifier	Oil money
Noun BY modifier	Student story

HH condition contained combinations for which the relation was highly frequent for both the modifier and head noun. For example, *mountain bird* can be interpreted using the relation noun LOCATED modifier, and this relation is highly frequent for both *mountain* and *bird*. The HL condition contained combinations for which the required relation was highly frequent for the modifier but not for the head noun. The LH condition contained combinations for which the relation was highly frequent for the head noun but not for the modifier.

These conditions were used in two experiments (reported as Experiments 1 and 3 in Gagné & Shoben, 1997). The procedure for both experiments was identical. Different items were used in the two experiments, however, so that we could demonstrate that the findings in Experiment 1 generalize to a new set of items. In both experiments, participants viewed the combinations one at a time on a computer screen and indicated whether they had a sensible interpretation. A set of nonsense fillers (e.g., *plastic rain*, *lawnmower lace*, and *scarf soda*) was included in the stimulus set. The participants pressed a key labeled ''yes'' to indicate that the item has a sensible interpretation and a key labeled ''no'' to indicate that the item did not have a sensible interpretation. The computer recorded the time between the onset of the stimulus and the key press. This response time was the primary dependent variable. Response time is the dominant dependent variable in the area of conceptual combination because it provides information about the ease with which two concepts can be combined. Short response times indicate that the concepts are readily combined. Long response times indicate that the concepts are difficult to combine. An alternative to measuring response time is to have the subject produce interpretations for each combination and then analyze the types of responses that are created (as in Wisniewski & Love, 1998). A problem with this offline measure, however, is that it provides information only about what the participants think the noun–noun phrase means and does not provide any information about the ease of creating the novel combination (see Gagné, 2000, for further discussion of the differences between online and offline measures). The CARIN theory's predictions concern the ease of comprehension and, thus, a response-time measure is the most appropriate.

As predicted by the CARIN theory, responses to the HH and HL combinations were faster than responses to the LH combinations, indicating that it was easier to determine the appropriate relation when it was highly frequent for the modifier than when it was not frequent. The difference between the HH and HL conditions was not significantly different, indicating that the frequency of the relation for the head noun constituent did not strongly affect response time.

Recall that all of the experimental items were intended to be interpretable and, therefore, the correct response for these items was ''sense.'' Thus, an accuracy measure could be computed for each item by tallying up the number of correct responses to the experimental items. The more difficult it is to select the required relation, the more likely it is that people will make a mistake (in this speeded online task) by indicating the item does not have a sensible interpretation. The accuracy data were consistent with the response-time data; accuracy was higher for the HH and HL combinations than for the LH combinations. Taken together, the response-time and accuracy data from these experiments indicate that relational information is used during conceptual combination. More specifically, the data demonstrate that the modifier's past usage with the required relation affects the ease of interpreting a novel combination.

To further test the CARIN theory, the response times for the items that were judged to have a sensible interpretation were fitted using the strength index described previously. If the assumptions of the CARIN theory are valid, then the strength index should be a good predictor of the ease with which a combined concept can be interpreted. To illustrate how a strength index was computed for each combination, consider the combinations *mountain bird* and *mountain magazine*. For *mountain*, the locative interpretation was used for 82% of all combinations using *mountain* as the modifier. The next most frequently used relations for this modifier were ABOUT, USES, and MADE OF, which, in order, were used for 10%, 2%, and 1% of the combinations using *mountain* as the modifier. The combination *mountain bird* requires the locative relation and, therefore, the strength index would be based on the proportion .82/(.82 + .10 + .02 + .01). The exponential decay function described previously would be applied to each of these proportions (i.e., the actual value for the numerator in this example would be .82 multiplied by −36 with an exponential function applied). For ease of explanation, however, I focus only on the proportions in this example. The strength index for *mountain bird* would be high. In contrast, the strength index for *mountain magazine* would be lower: .10/(.10 + .82 + .02 + .01). Notice that in this example, the modifier has a highly dominant relation and that this dominance is reflected in the strength index. For modifiers that do not have a highly dominant relation, the difference between the strength indexes for the most and second most frequent relations is not as dramatic. For example, the proportion of the four most frequent relations for *juvenile* are .34, .20, .15, and .10. Thus, the strength index for a combination using the most frequent relation is .34/(.34 + .20 + .15 + .10), whereas the strength index for the combination using the second most frequent relation is .20/(.20 + .34 + .15 + .10).

Recall that the CARIN theory predicts that the strength index should be a good predictor of the ease with which a combined concept can be interpreted. Indeed, we found that response time was highly correlated with this variable. The Pearson correlation was .44 in Experiment 1 and .35 in Experiment 2.

In addition to examining the correlation between response time and the strength index, we performed a stepwise regression using the strength index along with word frequency and word length for both the modifier and head noun. These additional variables were included because the stimuli differed in terms of word length and word frequency (how often a word appears in large text corpora such as the Brown corpus). Word frequency and word length are known to influence the time required to identify a word and, therefore, might be a source of variation in the response-time measure.

In forward stepwise regression, the best predictor is entered into the analysis first and additional predictors are entered only if they improve the regression model's ability to predict response time. In our analysis, the strength index variable accounted for the most variance relative to the other predictor variables in Experiment 1 and was second only to modifier word frequency in Experiment 2. The multiple R for the final regression model was .54 and .64 for Experiment 1 and Experiment 2, respectively. We were unable to directly compare the fits of this model to other models of conceptual combination because the CARIN model was the first model (to our knowledge) that predicts response times to novel combinations. However, the fits are similar to models in similar areas (Chumbley, 1986; Holyoak, 1978; Shoben, Cech, & Schwanenflugel, 1983).

The goal of more recent research has been to determine whether relational availability is affected by recent exposure to combinations with similar modifiers and head nouns. Recall that the CARIN theory assumes that the relational distribution used to compute the strength index is based on the modifier's history with various thematic relations. The question arises as to whether all previously encountered examples contribute equally or whether recent examples exert a stronger influence on conceptual combination.

To examine the influence of recently encountered combinations on conceptual combination, the experiments reported in Gagné (2001) used a priming procedure. This procedure involves examining the influence of a prime stimulus on responses to a target combination. In these experiments, novel modifier–noun combinations (e.g., *student vote*) were preceded by one of five prime combinations. The primes were manipulated such that the prime shared either the same modifier or head noun. In addition, the primes used either the same relation as the target combination (e.g., *student accusation* and *employee vote*) or a different relation (e.g., *student car* and *reform vote*). A neutral prime that used a different head noun and modifier as the target, but used the same relation, was included. Thus, the prime types were (a) same modifier/same relation, (b) same modifier/different relation, (c) same head noun/same relation, (d) same head noun/different relation, and (e) no shared constituent/same relation.

During the experiment, the trial using the target combination (e.g., *student vote*) was immediately preceded by a trial using one of the prime combinations. The conditions were counterbalanced so that each participant saw each target combination only once during the experiment, but across all participants each target combination was seen an equal number of times with each prime combination. Participants responded to both the prime and target combinations, and there was nothing in the procedure to differentiate prime and target trials. As in previous experiments (e.g., Gagné & Shoben, 1997) the task was to indicate whether the combination had a sensible interpretation. A set of nonsense filler items were included so that the participants could not determine prior to presentation of the stimulus whether the correct response was sense or nonsense.

The influence of the prime combination on relation availability was determined by comparing same-relation primes to different-relation primes. The CARIN theory predicts that the ease of combining two concepts is heavily influenced by the recent frequency with which the modifier and required relation have been paired. If a person has just used a particular relation in the context of a modifier (e.g., if the noun BY modifier has been used to link *student* and *accusation*), then this recent association between the relation and the modifier should strengthen the link between the relation and the modifier. Consequently, it should be easier to employ that relation during the interpretation of a subsequent combination (e.g., *student vote*) with the same modifier as the prime combination. In other words, if recent exposure to a combination using the same modifier as the target combination increases the ease of using a particular relation, then responding ''sense'' to the target *student vote* (a vote BY a student) should be faster when preceded by the prime *student accusation* (an accusation BY a student) than when preceded by the prime *student car* (a car FOR a student).

Primes containing the same head noun as the target were used to further test the CARIN theory's prediction that relational information is not associated with the head noun. That is, pairing a relation with a head noun should not affect the ease of selecting that relation for a subsequent presentation of a combination containing that head noun. If so, then responses to the target combination should be unaffected by whether the prime combination used the same relation (e.g., *employee vote*) or a different relation (e.g., *reform vote*). The data were consistent with these predictions. Relation priming was obtained only when the modifier constituent was in common. More recent evidence indicates that the modifier need not be identical for relation priming to occur; the same pattern of results is obtained when the modifier constituent of the prime combination is semantically similar to the target combination's modifier (Gagné, 2002).

To summarize, four main findings have emerged, and all are consistent with the basic assumptions of the CARIN theory. First, relational information is used during the interpretation of novel modifier–noun combinations. Second, the frequency with which a relation has been used with a particular modifier influences the ease of interpreting a novel combination using that modifier. Third, the frequency with which a relation has been used with a particular head noun does not influence the ease of interpreting a combination. Fourth, recency of a modifier–relation pairing also plays a role. The availability of a relation is affected by recent exposure to combinations with identical or semantically similar modifiers. These findings suggest that information about relational history is associated with the modifier rather than with the head noun.

IMPLICATIONS OF THE RELATION-BASED APPROACH

I have proposed that the CARIN theory is a more feasible theory of conceptual combination than are compositional and schema-based theories. The empirical data demonstrate that a modifier's relation history and recency of a relation are two factors that strongly affect the ease with which concepts can be combined, and these factors cannot be readily accounted for by competing theories. Thus, based on existing data, the relation-based approach appears to be a viable solution to the problem of how existing concepts can be used to generate new concepts.

Does this research have implications for research in areas other than conceptual combination? There are at least five ways in which this research can contribute to work in other domains. First, this work demonstrates that an experience-based approach is more likely to be fruitful than is an approach that relies solely on knowledge structures. Indeed, it is important to understand the nature of the stimuli and the frequency with which a person has been exposed to various items. In terms of conceptual combination, the frequency of specific modifier–relation pairings appears to be the most relevant aspect of past experience. A related point is that thematic relational information is a key contextual variable in the formation of novel combinations. Consequently, this work expands the type of absolute and relative frequency information that might affect stimulus processing in concept formation.

Second, this work demonstrates that it is possible to use natural stimuli and yet still examine the role of learning history. Gagné and Shoben (1997) approximated preexperimental learning history by constructing a corpus of modifier–noun combinations. The strength index, which was calculated based on information contained in this corpus, was highly correlated with the performance measure (response time). Thus, although many useful things about stimulus class formation in humans have been learned by using artificial stimuli, the research presented in this paper illustrates how one can use natural verbal stimuli and make use of the subject's preexisting abilities. The key is to determine which aspects of a subject's learning history are most likely to influence performance on a given task. This approach is especially useful when studying human subjects, because their long-term learning histories cannot be as easily controlled and manipulated as that of other organisms. Skinner (1977) and, more recently, Wixted and Gaitan (in press) have suggested that cognitive theories, and the mental processes they propose, serve implicitly as surrogates for a study of learning histories. In the CARIN model, attention to learning history is explicit, and the Gagné and Shoben (1997) research illustrates an attempt to reconstruct key aspects of such a history.

Third, this work on conceptual combination may inform work on contextual control of emergent stimulus classes. For example, in some contexts, a stimulus might be part of a class involving Stimuli B and C, but in other contexts the same stimulus might be in a different class (Steele & Hayes, 1991). Notice that in the case of conceptual combination, the modifier alters the context in which the head noun is interpreted and, thereby, changes the class to which the head noun belongs (and possibly not vice versa). To illustrate, in the context of the modifier *mountain*, the head noun *bird* is part of the class of "things that are located in the mountains." However, in the context of the modifier *plastic*, the noun *bird* is part of the class of "things that are made of plastic." By considering the role of the modifier (as in the studies presented in this paper), useful information can be gained about contextual control in cases in which there is competition among multiple contextual stimuli.

Fourth, this work can inform research on the transfer of function in stimulus class formation. Most research on this topic has a single function per class (e.g., Dougher & Markham, 1996). In contrast, in the case of conceptual combination there appears to be a merger of two functions, because both the modifier and head noun concepts contribute to the construction of a new concept and the modifier concept appears to govern which of several mutually exclusive functions is imparted. The functions are mutually exclusive because the head noun cannot participate simultaneously in more than one relation. For example, the concept *bird* cannot simultaneously be involved with the relations noun MADE OF modifier and noun LOCATED modifier. The research that I have conducted thus far indicates that the modifier's history with various relations heavily influences which of these relations will apply. This is a situation in which there is competition among multiple contexts (note that in the case of conceptual combination, the modifier forms the context for the head noun). In terms of more traditional stimulus class studies, it remains to be seen whether a similar finding will occur. It would be useful to know the extent to which function transfer is predicted by relation frequency in stimulus class formation studies in which more than one function per class is transferred.

Finally, the approach that I have described is intended to predict performance averaged over groups of research participants because, traditionally, this has been the goal of researchers who study conceptual combination in humans (Murphy, 1988, 1990; E. E. Smith

& Osherson, 1984; E. E. Smith, Osherson, Rips, & Keane, 1988; Wisniewski, 1997). This approach, however, presumably can be translated to situations in which the goal is to predict an individual's performance. To do so, it is necessary to establish the kinds of combinations to which the individual has been exposed. This might be done, for example, by having a subject generate lists of combinations in response to various modifier concepts (e.g., list all the combinations that start with *mountain*) or indicate which combinations on a list he or she has encountered. Such procedures would allow the modifier relational distribution to be calculated, at which point the investigation could proceed just as in the study of groups of participants. The only difference is that, for examining behavior at the level of individuals, the corpus is specifically tailored for the individual under investigation and is meant to reflect the specific learning history of that individual. In the case of studying average behavior over a group of subjects, the corpus is based on a set of items that most (if not all) people will have experienced and reflects the learning history of the typical participant. Although these approaches differ in their goals, research directed at studying the "average" participant can identify variables that are important to include in studies that examine behavior at an individual-subject level. Conversely, it will be interesting to see whether investigators who are accustomed to focusing on individual behavior in the context of artificial stimulus classes can develop experimental models that advance the understanding of conceptual combination.

To conclude, there are several commonalities between the CARIN theory and models of associative learning and memory. Due to this compatibility, it seems likely that, by evaluating and integrating principles inherent to both approaches in theories of conceptual combination and stimulus class formation, researchers can gain a better understanding of the variables that control performance in their respective areas of research. In particular, the approach outlined in this paper is best suited for understanding experience-based classes of relations and their effect on the formation of novel combinations. This work can be joined with existing research on stimulus class formation to study simultaneously the complexities of stimulus class formation and class expansion.

REFERENCES

Anderson, J. R. (1983). *The architecture of cognition.* Hillsdale, NJ: Erlbaum.

Anderson, J. R. (1990). *The adaptive character of thought.* Hillsdale, NJ: Erlbaum.

Anderson, J. R. (2000). *Learning and memory: An integrated approach.* New York: Wiley.

Anderson, J. R., & Bower, G. H. (1974). A propositional theory of recognition memory. *Memory & Cognition, 2,* 406–412.

Anderson, J. R., & Schooler, L. L. (1991). Reflections of the environment in memory. *Psychological Science, 2,* 396–408.

Anderson, R. B., Tweney, R. D., Rivardo, M., & Duncan, S. (1997). Need probability affects retention: A direct demonstration. *Memory & Cognition, 25,* 867–872.

Baer, D. M. (1981). The imposition of structure on behavior and the demolition of behavioral structures. *Nebraska Symposium on Motivation, 29,* 217–254.

Chumbley, J. (1986). The roles of typicality, instance, dominance, and category dominance in verifying category membership. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12,* 257–267.

Clark, E. V. (1987). The principle of contrast: A constraint on language acquisition. In B. MacWhinney (Ed.), *Mechanisms of language acquisition: The 20th annual Carnegie symposium on cognition* (pp. 1–33). Hillsdale, NJ: Erlbaum.

Davison, M., & Nevin, J. A. (1999). Stimuli, reinforcers, and behavior: An integration. *Journal of the Experimental Analysis of Behavior, 71,* 439–482.

Donahoe, J. W., & Palmer, D. C. (1994). *Learning and complex behavior*. Needham Heights, MA: Allyn & Bacon.

Dougher, M. J., & Markham, M. R. (1996). Stimulus classes and the untrained acquisition of stimulus function: Advances in psychology. In T. R. Zentall & P. M. Smeets (Eds.), *Stimulus class formation in humans and animals* (pp. 137–152). New York: Elsevier Science.

Dymond, S., & Rehfeldt, R. A. (2001). Supplemental measures of derived stimulus relations. *Experimental Analysis of Human Behavior Bulletin, 19,* 8–12.

Gagné, C. L. (2000). Relation-based combinations versus property-based combinations: A test of the CARIN theory and dual-process theory of conceptual combination. *Journal of Memory and Language, 42,* 365–389.

Gagné, C. L. (2001). Relation and lexical priming during the interpretation of noun-noun combinations. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27,* 236–254.

Gagné, C. L. (2002). Lexical and relational influences on the processing of novel compounds. *Brain and Language, 81,* 723–735.

Gagné, C. L., & Shoben, E. J. (1997). Influence of thematic relations on the comprehension of modifier-noun combinations. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23,* 71–87.

Gelman, S. A., & Markman, E. M. (1985). Implicit contrast in adjectives vs. nouns: Implications for word-learning in preschoolers. *Journal of Child Language, 12,* 125–143.

Gluck, M. A., & Bower, G. H. (1988). From conditioning to category learning: An adaptive network model. *Journal of Experimental Psychology: General, 117,* 227–247.

Godden, D. R., & Baddely, A. D. (1975). Context-dependent memory in two natural environments: On land and under water. *British Journal of Psychology, 66,* 325–331.

Hampton, J. A. (1988). Overextension of conjunctive concepts: Evidence for a unitary model of concept typicality and class inclusion. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14,* 12–32.

Hampton, J. A. (1997). Conceptual combination: Conjunction and negation of natural concepts. *Memory & Cognition, 25,* 888–909.

Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior, 13,* 243–266.

Herrnstein, R. J. (1990). Behavior, reinforcement and utility. *Psychological Science, 1,* 217–224.

Holyoak, K. (1978). Comparative judgments with numerical reference points. *Cognitive Psychology, 10,* 203–243.

Komatsu, L. K. (1992). Recent views of conceptual structure. *Psychological Bulletin, 112,* 500–526.

Levi, J. N. (1978). *The syntax and semantics of complex nominals.* New York: Academic Press.

Luce, R. (1959). *Individual choice behavior*. New York: Wiley.

Markman, A. B., & Wisniewski, E. J. (1997). Similar and different: The differentiation of basic-level categories. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23,* 54–70.

Markman, E. M. (1989). *Categorization and naming in children: Problems of induction.* Cambridge, MA: MIT Press.

Medin, D. L., & Shoben, E. J. (1998). Context and structure in conceptual combination. *Cognitive Psychology, 20,* 158–190.

Murphy, G. L. (1988). Comprehending complex concepts. *Cognitive Science, 12,* 529–562.

Murphy, G. L. (1990). Noun phrase interpretation and conceptual combination. *Journal of Memory and Language, 29,* 259–288.

Murphy, G. L., & Medin, D. L. (1985). The role of theories in conceptual coherence. *Psychological Review, 92,* 289–316.

Nevin, J. A., & Grace, R. C. (2000). Behavioral momentum and the law of effect. *Behavioral and Brain Sciences, 23,* 73–130.

Raaijmakers, J. G. W., & Shiffrin, R. M. (1981). Search of associative memory. *Psychological Review, 88,* 93–134.

Rescorla, R. A., & Wagner, A. R. (1972). A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement. In A. H. Black & W. F. Prokasy (Eds.), *Classical conditioning: Vol. 2. Current theory and research* (pp. 64–99). New York: Appleton-Century-Crofts.

Roper, K. L., & Zentall, T. R. (1993). Directed forgetting in animals. *Psychological Bulletin, 113,* 513–532.

Rumelhart, D., & Abrahamson, A. (1973). A model for analogical reasoning. *Cognitive Psychology, 5,* 1–28.

Schooler, L. J., & Anderson, J. R. (1997). The role of process in the rational analysis of memory. *Cognitive Psychology, 32,* 219–250.

Shoben, E. J., Cech, C., & Schwanenflugel, P. (1983). The role of subtractions and comparisons in comparative judgments involving numerical reference points. *Journal of Experimental Psychology: Human Perception and Performance, 9,* 226–241.

Sidman, M. (2000). Equivalence relations and the reinforcement contingency. *Journal of the Experimental Analysis of Behavior, 74,* 127–146.

Skinner, B. F. (1938). *The behavior of organisms: An experimental analysis.* New York: Appleton-Century.

Skinner, B. F. (1977). Why I am not a cognitive psychologist. *Behaviorism, 5,* 1–10.

Skinner, B. F. (1981). Selection by consequences. *Science, 213,* 501–504.

Smith, E. E., & Osherson, D. N. (1984). Conceptual combination with prototype concepts. *Cognitive Science, 8,* 337–361.

Smith, E. E., Osherson, D. N., Rips, L. J., & Keane, M. (1988). Combining prototypes: A selective modification model. *Cognitive Science, 12,* 485–527.

Smith, S. M. (1979). Remembering in and out of context. *Journal of Experimental Psychology: Human Learning and Memory, 5,* 460–471.

Steele, D., & Hayes, S. C. (1991). Stimulus equivalence and arbitrarily applicable relational responding. *Journal of the Experimental Analysis of Behavior, 56,* 519–555.

Storms, G., De Boeck, P., Van Mechelen, I., & Ruts, W. (1996). The dominance effect in concept conjunctions: Generality and interaction aspects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 1266–1280.

Storms, G., Ruts, W., & Vandenbroucke, A. (1998). Dominance, overextensions and the conjunction effect in different syntactic phrasings of concept conjunctions. *European Journal of Cognitive Psychology, 10,* 337–372.

Tulving, E., & Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review, 80,* 359–380.

White, K. G., & Wixted, J. T. (1999). The psychophysics of remembering. *Journal of the Experimental Analysis of Behavior, 71,* 91–113.

Wiseman, S., & Tulving, E. (1975). A test of confusion theory of encoding specificity. *Journal of Verbal Learning and Verbal Behavior, 14,* 370–381.

Wisniewski, E. J. (1996). Construal and similarity in conceptual combination. *Journal of Memory and Language, 35,* 434–453.

Wisniewski, E. J. (1997). When concepts combine. *Psychonomic Bulletin and Review, 4,* 167–183.

Wisniewski, E. J., & Love, B. C. (1998). Relations versus properties In conceptual combination. *Journal of Memory and Language, 38,* 177–202.

Wixted, J. T., & Gaitan, S. C. (in press). Cognitive theories as reinforcement history surrogates: The case of likelihood ratio models of human recognition memory. *Animal Learning & Behavior.*

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